

**FIRST-ROUND VISION 21 SELECTIONS AND
SUMMARY OF PUBLIC ABSTRACTS
and
IMPORTANT GENERAL INFORMATION
FOR SECOND-ROUND (MARCH 31, 2000) APPLICANTS**

Area of Interest A

To Fabricate and Test an Advanced Non-polluting Turbine Drive Gas Generator (Clean Energy Systems, Inc., Sacramento, CA)

The objective of the Clean Energy Systems (CES) project is to fabricate and test a novel turbine drive gas generator. The gas generator is smaller and simpler when compared to generators of equal output, such as boilers, and, when combined with advanced steam turbines, can produce high thermal efficiencies. Rather than burning a hydrocarbon fuel with air, the gas generator produces a turbine drive gas by combustion of a clean fuel, such as natural gas or syngas derived from coal, with oxygen (O_2). Water is injected to produce the working fluid and to control the drive gas temperature. In the case of combustion of methane and oxygen, the turbine drive gas is composed of steam (~90% by volume) and carbon dioxide (CO_2). The gas temperature and pressure can be controlled to drive steam turbines that operate at pressures of 3,000 psia, or higher, and temperatures of 2,600 °F to 3,200 °F. The gas generator is a key element in CES's operational power system that releases no combustion products to the atmosphere, and provides a cost-effective means of separating and conditioning CO_2 for disposition.

The project includes the fabrication of a test unit (simulating a 10-MW generator) to be used in a test program designed to demonstrate the non-polluting aspects of the gas generator, evaluate performance, and verify operational characteristics. The generator will burn methane with oxygen. Pressure and temperature data will be obtained to characterize the device's operation and performance. Exhaust gas sampling will be used to determine gas composition.

The controlled combustion process, developed by CES, is the key to creating the non-polluting powerplant. In an operational system, the working fluid will drive multistage steam turbines, then enter a condenser, where the CO_2 and H_2O could be easily separated. The plant process can separate and prepare the CO_2 as a byproduct, or for sequestration in an underground formation (liquefied and pressurized to 5,000 psia), at a parasitic power penalty of less than 4%. The water will be re-circulated to the gas generator (that is, the water circuit is closed). A small excess of water is produced which can be used as make-up water in the plant cooling system, used for co-generation, or otherwise disposed of. A unique feature of CES's plant concept is that it is a net producer of water. The plant can be located in areas that are "water sensitive." The system draws little or no water from local sources and can be air cooled where climate permits.

Powerplants that combine the CES gas generator and advanced steam turbines (operating at present-day gas turbine temperatures, ~2,600 °F, and at pressures on the order of 3,000 psia) are projected to achieve net powerplant efficiencies in the range of 60% - 65% (LHV), with no

emissions to the atmosphere, compliant with Vision 21 goals. As oxygen cost decreases with the development of ion transfer membrane separation technology, economics of the CES powerplant concept will be enhanced.

Advanced Hydrogen Transport Membranes for Vision 21 Fossil Fuel Plants (Eltron Research, Inc., Boulder, CO, and Coors, Chevron, United Catalyst, McDermott, Argonne and Oak Ridge National Laboratories)

The objective of this project is to develop an environmentally benign, inexpensive, and efficient method for separating hydrogen from gas mixtures produced during industrial processes, such as coal gasification. This goal will be accomplished by employing dense ceramic membranes based on materials with a demonstrated ability for rapid proton and electronic conduction. The primary technical challenges in achieving the goals of this project will be to optimize the composition and microstructure of ceramic membrane materials for proton/electron conductivity and stability, and to develop dense membrane structures that enable a hydrogen (H_2) separation rate in excess of 10 ml/min/cm². Other aspects of this developing technology to be refined during this project include catalysis, ceramic processing methods, and separation unit design.

It is anticipated that the proposed approach for hydrogen separation will provide the following benefits:

- (1) Since the membrane materials are inexpensive and are mixed proton and electronic conductors, the system design is inherently simple and economical, requiring no external circuitry or applied potential.
- (2) Because the membranes are nonporous, only hydrogen will be transported through the membrane, without contributions from break-through of other gases. Accordingly, the separated hydrogen will be of high purity, and these high-density membranes are not subject to problems associated with pore clogging.
- (3) The conduction mechanism in these materials occurs at elevated temperatures compatible with incorporation into chemical processing streams.
- (4) In addition to hydrogen separation, this ceramic membrane technology can be used to facilitate numerous chemical processing applications.

This project will proceed by appropriately adjusting ceramic lattice substituents to achieve an optimal compromise between mixed conductivity and stability of membrane materials under anticipated operating conditions. Concurrently, multiphase materials with maximum ambipolar conductivity will be developed, and supported thin-film membranes of promising materials will be fabricated and tested. Conductivity characteristics and hydrogen separation rates will be determined for selected membrane structures, and candidate compositions employed in laboratory-scale high-pressure hydrogen separation units. Information gained during laboratory testing will be used to develop a prototype hydrogen separation unit and generate a strategy for technology scale-up in the final stages of the project.

Critical Components for Direct Fuel Cell/Turbine Ultra-High-Efficiency System (FuelCell Energy, Inc., Danbury, CT, and Allison Engine and Capstone Turbine)

FuelCell Energy (FCE) will conduct developmental activities to support the design of an ultra-high-efficiency (UHE) hybrid powerplant based on FCE's direct fuel cell. Studies conducted to date indicate that this hybrid system should be capable of delivering energy efficiencies of 65% (near term) to near 80% in the long term (by ~2015). The system is projected to meet the goals of the Vision 21 program because of the following features:

- (1) The high efficiencies possible in the long term exceed the 75% LHV goal for natural gas.
- (2) Because of that high efficiency, the goal of halving CO₂ emissions relative to a 35% (HHV) efficient coal system is met.
- (3) SO_x and NO_x levels are projected to be an order of magnitude below the Vision 21 target of 0.01 lb/MMBtu. Non-methane hydrocarbon emissions (NMHC) and particulate emissions are projected to be negligible for both the simple cycle as well as the hybrid system.
- (4) The system has the potential to meet the target of significantly reducing the capital cost for Vision 21 plants.

Beyond these Vision 21-specific features, the proposed hybrid system also has a number of attractive features that apply across a wide range of system sizes and that will apply in near-term, mid-term, and long-term systems. Also, the system will be applicable to natural-gas as well as coal-gas systems. The purpose of this project is to take the necessary first steps toward that very attractive long-term powerplant product. These first steps focus on the critical technology needs that must be addressed to move the technology toward such high performance levels. First, the fuel cell performance must be increased to the point where faradic fuel utilization in the >90% range is achievable. Fuel utilization levels are typically now in the mid-seventies, with near-term projections in the mid-80s. The second area that must be addressed is the range of fuel cell/turbine integration issues.

One of the most attractive features of FCE's hybrid system is the degree of independence between the fuel cell and turbine sections (which comes from the fact that waste heat is transferred indirectly from the atmospheric pressure fuel cell system to the turbine).

Four major activities will be performed:

- (1) High-Utilization Fuel Cell Development: Approaches to achieving very high efficiency from the fuel cell section of the plant will be investigated. This includes experimentally evaluating the fuel cell networking approach, in which fuel cells are used to "bottom" other fuel cells. Two 20-kW fuel cell stacks will be used for this test. Understanding gained from this work will have spin-off benefits to the simple cycle product and even to other fuel cell systems.
- (2) Development of Key System Components: These key components include a modified version of the anode exhaust oxidizer currently used in the simple-cycle plant, and heat exchange equipment that is specific to the cycle.

(3) Subscale Testing of a direct fuel cell/turbine hybrid system will be done to develop key design information needed for fuel cell/turbine integration. This will be done cost-effectively by modifying FCE's existing fuel cell test facility with the necessary heat exchange equipment and a commercially available microturbine. A 250-kW fuel cell stack (built under FCE's technology development program) will be used for this test.

(4) Conceptual Design of a 40-MW Vision 21 ultra-high-efficiency powerplant will be done in concert with the above tasks. Initial work will guide the hardware-related activities, and the results of the tests will be fed into an updated conceptual design.

Zero Emissions Power Plants Using SOFCs and Oxygen Transport Membranes (Siemens Westinghouse Power Corporation, Pittsburgh, PA, and Praxair)

Siemens Westinghouse Power Corporation, in conjunction with Praxair, Inc., will conduct a 30-month project to develop the technology that would enable development of zero emissions Vision 21 powerplants based on solid oxide fuel cells (SOFCs) and ceramic oxygen transport membranes (OTMs). Their approach to achieve a zero-emissions SOFC power system is to modify the design of a tubular SOFC module to incorporate an afterburner stack of tubular oxygen transport membranes. Oxygen transported through the membrane will be used to oxidize the SOFC-depleted fuel in the anode exhaust to carbon dioxide and steam. The carbon dioxide can then be easily separated, for eventual sequestration, by condensing the steam.

The focus of the project is to develop ceramic oxygen transport membranes that are chemically and mechanically stable in the SOFC-depleted fuel environment and have an adequate oxygen flux to economically oxidize the SOFC-depleted fuel to completion. This work will specifically include:

- System study to set cost and oxygen flux targets for OTMs
- Selection of lead candidate materials for OTMs and their characterization for physical, chemical, and mechanical properties
- Fabrication of the selected material in tubular OTMs, and their testing in SOFC-depleted fuel
- Conceptual design of the SOFC and OTM module(s).

Area of Interest B

Systems Integration Methodology (National Fuel Research Center, Irvine, CA, and KraftWork Systems, Inc., and Spencer Management Associates)

A multi-disciplinary team led by the National Fuel Cell Research Center of the University of California at Irvine (NFCRC/UCI) will define the system engineering issues associated with the integration of key components and subsystems into powerplant systems that meet the

performance and emission goals of Vision 21. Numerous fuels, fuel processing, power generation, and emission control technologies will be analyzed to identify those combinations that achieve Vision 21 goals. These high-performance plants will then be examined in detail to identify key technical, operability, and economic factors that would affect the integration of the components and subsystems into a viable Vision 21 powerplant. The study will provide the emerging post-deregulation, market-based power industry with insight concerning opportunities to apply a variety of advanced technologies in their quest to generate low-cost power for their customers. The study will also identify areas requiring further research and development.

The configurations to be analyzed in depth would be identified through a screening study in which a broad matrix of fuels, fuel processing technologies, power system technologies, and emission control technologies would be evaluated in a consistent manner. Those combinations that closely approach or meet the Vision 21 goals of 60% efficiency (HHV) for coal-based systems and 75% efficiency (LHV) for gas-based systems would be selected for further detailed analyses to identify the technical parameters that affect component/subsystem integration.

To complete the identification of factors affecting integration, a concise assessment of the emerging, post-deregulation power generation industry will identify market-driven factors affecting preferred powerplant design. The advent of deregulation and the rise of merchant power production will impact the historical relationship among capital cost, fuel cost, and O&M costs. Also, the economics associated with meeting acceptable levels of reliability, availability, and maintainability will affect design considerations when integrating and controlling increasingly complex powerplants, and will impact the historic relationship between efficiency and capital cost. By including these factors in the analyses, early definition can be made of component/subsystem design modifications and of operability and cost issues affecting successful systems integration.

The emphasis of the project will be on systems producing electricity as the major revenue stream. When appropriate, however, co-production of high-value chemicals or alternative fuel forms will be considered as will production of thermal energy for industrial or district heating use. The technology levels considered will be based on projected technical and manufacturing advances being made in industry and on advances identified in current and future government-supported research such as the Clean Coal Technology program, Combustion 2000 (LEBS and HIPPS), Advanced Turbine Systems program, Low-Cost Advanced Fuel Cell programs, and the Flexible Gas Turbine Systems program.

A power system computer simulation program recently developed at NFCRC/UCI to analyze fuel cell-based power systems will be used as the major analysis tool in conjunction with the State-of-the Art Preprocessing Program (SOAPP), recognized as the industry standard for gas turbine analysis. The SOAPP powerplant simulation has been used for well over two decades in numerous DOE-, EPRI-, and NASA-sponsored projects including the Combustion 2000/HIPPS program and the Advanced Turbine Systems program. This experience will be combined with the latest technical information on advanced gas turbines, fuel cells, and fuel processing from the Team's industrial partners to assure that realistic engineering practices are maintained.

Area of Interest C

Software Integration for Vision 21 Virtual Demonstration (Fluent, Inc., Lebanon, NH, and ABB Alstom Power, Aspen Technology, Intergraph, and West Virginia University)

To fulfill the goals of Vision 21 program, DOE has identified the need for “an integrated suite of codes that includes submodels for components and subsystems, dynamic response and process control, and visualization capabilities” called the “virtual demonstration.” This project addresses this need.

The knowledge about the process gained in developing and testing Vision 21 technology modules will be captured by models that describe the process at different levels of granularity: e.g., flow sheet-level models such as Aspen Plus, CFD models such as FLUENT, and proprietary design models used by manufacturers such as ABB Alstom Power. Currently these models are used separately to design and trouble-shoot different aspects of the process. Also, the physical properties used in the different models are often not consistent. The knowledge captured through these models must be integrated so that the designers have the ability to search the process parameter space to a greater depth and determine optimum process configurations. This capability is a crucial need for designing Vision 21 systems.

The overall vision is to develop an integrated suite of modeling codes that seamlessly integrate flow sheet-level models and equipment-level models. To demonstrate the envisioned software integration technology, Fluent chose the flow sheet model Aspen Plus as the centerpiece. They will integrate the CFD model FLUENT and proprietary design codes from ABB Alstom Power to Aspen Plus. They will use CAPE-OPEN, the *de facto* international standard for exchanging information between flow sheet-level models, as the basis for the integration. It is anticipated that the CAPE-OPEN standards will need to be extended to accommodate information exchange between the flow sheet-level model and the detailed models such as CFD. In doing that, Fluent will strive to create open standards agreed upon by others. For that purpose they will seek the advice of an Advisory Board consisting of other Vision 21 participants. Eventually the technology (excluding proprietary codes) developed under this project would be available to other CFD and equipment vendors.

For demonstrating the capability of the integrated software suite, Fluent will conduct simulations of a conventional steam plant and a combined cycle plant. While these are not Vision 21 plant concepts, it is believed that these plants have a sufficient number of features to thoroughly verify that the integrated software suite will be suitable for modeling Vision 21 systems when they are developed. In these simulations Fluent will test the ability of detailed CFD models and proprietary models to interact with flow sheet-level models. With the simulation results Fluent will also demonstrate the visualization capability--that is, the ability to navigate a process flow diagram and easily access CFD-level details.

Upon the completion of this project, a general methodology and open standards for the integration of equipment-level models with flow sheet models will emerge. Using existing components such as Aspen Plus and FLUENT will ensure that the technology is immediately available for use by U.S. industry. The open standards will allow other companies, including Fluent's competitors, to easily plug their models into the integrated software suite (*Plug and Play*

capability). Embedding detailed models in flow sheet-scale models will enable the reuse of detailed equipment-level knowledge and improve the design of Vision 21 systems.

**IMPORTANT GENERAL INFORMATION FOR
SECOND-ROUND (MARCH 31, 2000) APPLICANTS**

Now that the first round of Vision 21 proposals has been submitted and reviewed and selections have been made, there are several items that DOE would like to draw potential applicants' attention to. Heeding these elements can strengthen your application as well as assist DOE in conducting reviews and making selections. Please note the following:

1. The Vision 21 solicitation contains the following Program Policy Factor. Please review it to see how past selections could influence future selections.

Programmatic Balance: It may be desirable to select one or more projects that represent a diversity of technology approaches and methods. Further, DOE desires to make roughly equal numbers of awards in each of the three Areas of Interest.

2. The Vision 21 solicitation has a 50-page limit for Volume II, Technical Application. Applicants are strongly encouraged to stay within this limit. Applicants should not try to circumvent the limit through referenced documents, attachments, and creative pagination. Submissions of greater length will be judged by DOE to detract from the quality of the proposal.
3. Section IV-H of the Vision 21 solicitation described an evaluation criterion that was titled, "Economic Benefit to the United States." As noted in the original solicitation, applicants must provide a separate discussion in Volume I, not exceeding five (5) pages in length, explaining how the proposed work will benefit the economic interest of the United States. Applicants should quantitatively describe the realistic economic impact that successful deployment of the proposed technology would generate. Factors such as (1) market share, (2) numbers of jobs created, and (3) projected gross sales **for the proposed technology** should be considered.
4. Section C.1 of the Vision 21 solicitation notes that applicants are to complete the appropriate budget form and provide all supporting cost data as specified by the instructions. The applicant is also to provide a detailed budget, for the entire period of support, with written justification sufficient to allow evaluation of the itemized list of costs provided. DOE recommends that applicants make a sincere effort to be in full compliance with this requirement.
5. Section C.1 also requires that applicants complete, among other things, Representations and Certifications as well as an Environmental Questionnaire. Applicants are encouraged to be accurate and comprehensive in completing these forms.